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COMPOSITES THEORY AND PRACTICE

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PHYSICAL AND MECHANICAL CHARACTERIZATION OF STRUCTURAL LIGHTWEIGHT CONCRETE WITH SYNTHETIC ALOXITE ADDITIVE

The recent years of intensive development in construction as well as growing demands has resulted in much greater attention paid to concretes for special applications, such as lightweight structural concretes. The advantage of lightweight structural concretes lies in the lower weight of the construction elements (the density of lightweight concretes equals less than 2000 kg/m^3) and high strength parameters, which further lead to lower production costs. Moreover, lightweight concretes can be considered so-called ”green products”, as lightweight aggregates received from waste materials, such as fly ashes, are used for their production. Conducted research has shown that aloxite usage has a great influence on the physical and mechanical properties of lightweight structural concretes. The best results were achieved for a concrete mix with an additive of fine-grained aloxite particles. The presence of aloxite fine fractions (F280) in concrete contributed to condensation of the cement paste structure and strengthening the interfacial transition zone between the porous lightweight aggregate and cement paste, improving the physical and mechanical properties of the concrete composite. It was shown that the compressive strength of concrete samples with an aloxite additive increases by about 25÷35% in relation to reference samples. Moreover, the aloxite additive improved the resistance to abrasion by about 30÷40% in comparison to concrete made without additives. In addition, the research proved that aloxite particles show a plasticizing effect and facilitate stirring of the concrete mix, especially in the presence of lightweight aggregate, which leads to a more homogeneous structure of concrete and improvement of concrete tightness by about 35÷50% in relation to the reference concrete.

Keywords: lightweight concrete, aloxite, physical and mechanical properties, SEM analysis

FIZYKOMECHANICZNA CHARAKTERYSTYKA LEKKICH BETONÓW KONSTRUKCYJNYCH Z DODATKIEM SYNTETYCZNEGO TLENKU GLINU

Intensywny rozwój budownictwa w ostatnich latach i rosnące wymagania użytkowe sprawiają, że coraz większą uwagę zwraca się na betony o specjalnych zastosowaniach, takie jak np. betony lekkie. Zaletą stosowania betonów lekkich konstrukcyjnych jest obniżenie wagi elementów konstrukcyjnych przy zachowaniu wymaganych parametrów wytrzymałościowych, co z kolei przekłada się na obniżenie kosztów produkcji. Ponadto betony lekkie można zaliczyć do tzw. „produktów zielonych” z uwagi na zastosowanie do ich wytwarzania lekkich kruszyw otrzymywanych z materiałów odpadowych, np. popiołów lotnych. W przeciwieństwie do powszechnie stosowanych w technologii betonu dodatków pucolanowych, np. popiołów lotnych, w przedstawionych badaniach zastosowano syntetyczny tlenek glinu w dwóch granulacjach. Przeprowadzone badania wykazały, że zastosowanie elektrokorundu zwykłego ma duży wpływ na właściwości fizykomechaniczne lekkich betonów konstrukcyjnych. Najlepsze wyniki uzyskano dla mieszanek betonowych z dodatkiem drobnoziarnistego elektrokorundu. Obecność drobnych frakcji tlenku glinu (F280) przyczyniła się do zagęszczenia struktury zaczynu cementowego i zwiększenia przyczepności matrycy cementowej do kruszywa lekkiego, co z kolei spowodowało wzrost parametrów fizykomechanicznych kompozytu cementowego. Wykazano, że wytrzymałość na ściskanie próbek betonowych z dodatkiem tlenku glinu zwiększa się, w odniesieniu do próbek kontrolnych, średnio o ok. 25÷35%. Ponadto dodatek tlenku glinu zwiększył odporność betonu na ścieranie o około 30÷40% w porównaniu do betonu wykonanego bez żadnych dodatków. Dodatkowo badania wykazały, że tlenek glinu wykazuje działanie uplastyczniające, ułatwia mieszanie mieszanki betonowej szczególnie w obecności kruszywa lekkiego, co pozwala uzyskać jednorodną strukturę betonu oraz wpływa na poprawę szczelności betonów, podwyższając ją nawet o 35÷50% w stosunku do betonów referencyjnych.

Słowa kluczowe: betony lekkie, syntetyczny tlenek glinu, fizykomechaniczne właściwości, analiza SEM

INTRODUCTION

The recent years of intensive development in construction, as well as growing demands, has resulted in much greater attention paid to concretes for special applications, such as lightweight structural concretes. The advantage of lightweight structural concretes lies in the lower weight of construction elements (the density of lightweight concretes equals less than 2000 kg/m^3) and high strength parameters, which further lead to lower production costs. Moreover, lightweight concretes can be considered so-called ”green products", as we use lightweight aggregates received from waste materials, such as fly ashes, for their production [1-3]. Besides their undisputed advantages, lightweight concretes also have some disadvantages. In the designing process and production of the concrete mixture, it is crucial to pay special attention to its consistency. A liquid consistency causes the lightweight aggregate to undergo the flotation process, which further results in separation of particular components of the concrete mixture. In the case of a less liquid consistency on the other hand, concrete workability is limited due to the high water demand of the lightweight aggregate. In such cases, it is necessary to initially wet the lightweight aggregate or apply additions like fly ashes, blast furnace slag etc. to condense the structure of the cement paste, and improve the workability of the concrete mixture [4]. Instead of pozzolan additions, such as fly ashes, commonly applied in concrete technology, in this research aloxite in two granulations was applied. Previous studies have indicated that concrete strength and high resistance to abrasion depends on the aggregate property and dosage, concrete strength, mixture proportions, the use of supplementary cementitious materials, fiber addition, curing conditions and finishing surfaces [5-7]. The upper layers of concrete with high resistance to abrasion are usually composed of high class cements, water, sand and coarse aggregate. To strengthen the concrete surface, corundum, electrocorundum, silicon carbide and iron filings with diameters below 3 mm can be applied [8].

EXPERIMENTAL PART

Concrete mixture ingredients and formula

Lightweight concretes that are the subject of the research are: referential - without additions (reference samples) and with the addition of aloxite in two different granulations. In the concrete mixtures the following materials were used: cement CEM I 42.5 R consistent with norm PN-EN 197-1 (Table 1). Pollytag lightweight aggregate fraction 4÷14 mm made of fly ashes (Table 2), sand, water and a superplasticizer admixture. In order to increase the abrasive strength of the concrete, an addition of synthetic aloxite was applied with the granulations of F80 (212÷180 μm) and F280 (36.2 μm ±1.5%) (Fig. 1), which showed high thermal conductivity and low thermal expansion. Table 3 presents its physicochemical properties.

Three formulae of concrete mixtures were used in the research and their ingredients are presented in Table 4. The high amounts of cement are characteristic for high strength lightweight concretes [9]. The high amounts of aloxite were applied to improve the workability of a concrete mixture with high amounts of cement binder on the one hand and to enhance the mechanical properties on the other. In order to prepare a cement composite, cement paste with or without an addition of aloxite particles was mixed with the superplasticizer and lightweight aggregate. The samples were condensed on a vibrating table, and after 48 hours of hardening they were demoulded and kept in water at 20°C until testing the physicomechanical properties.

TABLE 1. **Properties of CEM I 42.5 R [Lafarge] cement**
TABELA 1. **Właściwości cementu CEM I 42.5 R [Lafarge]**

Specific surface	3210 cm²/g
Initial setting time	194 min
Final setting time	251 min
Compressive strength after 2 days	28.1 MPa
Compressive strength after 28 days	56.2 MPa
Bulk density	3.09 g/cm³
Water demand	27.9%
Sulfate contents	3.26%
Chloride contents	0.069%
Alkalies contents	0.76%

TABLE 2. **Properties of Pollytag aggregate**
TABELA 2. **Właściwości kruszywa Pollytag**

Loose bulk density in dry state		650÷850 kg/m^3
Density		till 1.45 g/cm^3
Resistance to grain crushing		till 10 MPa
Grain porosity		about 40%
Volume of free spaces between aggregate 4÷12mm filled with air in loose state		about 45%
Volume of free spaces between aggregate 4÷12mm filled with air in dense state		about 37%
Water absorbability after 30 minutes		20 ±4%
Water absorbability after 24 hours		22 ±4%
Abrasive indicator		abaut 30%
Freeze resistance		≤ 5% mass loss
Heat resistance after 5 cycles		abaut 3% mass loss
Natural radioactivity		Below level acceptable for building materials
Approximate chemical composition	SiO_2	58%
	Al_2O_3	22%
	CaO	2.2%
	MgO	1.4%
	SO_3	0.3%

TABLE 3. **Physical and chemical properties of aloxite additive**
TABELA 3. **Właściwości fizykochemiczne dodatku syntetycznego tlenku glinu**

Amount of Al_2O_3	94.5÷97%
Admixtures	TiO_2, SiO_2, Fe_2O, CaO, MgO
Hardness	9 according to Mosh scale
Density	3.90 ±0.05 g/cm^3
Bulk density	1.52÷1.87 g/cm^3 in relation to granulation
Grain shape	Sharp-edged

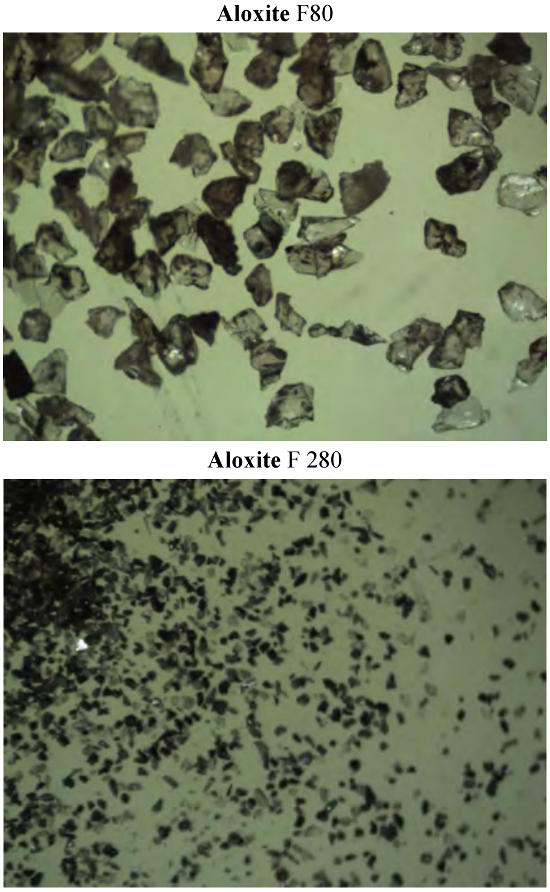


Fig. 1. Comparison of aloxite size and shape at 7x magnification

Rys. 1. Porównanie wielkości i kształtu dodatku syntetycznego tlenku glinu przy powiększeniu 7x

TABLE 4. **Composition of concrete mix in relation to aloxite granulation (for 1 m^3)**

TABELA 4. **Skład mieszanek betonowych w zależności od zastosowanej granulacji elektrokorundu (na 1 m^3)**

Component	Recipe		
	Reference concrete	Concrete with aloxite F80	Concrete with aloxite F280
Cement [kg]	600	600	600
Aggregate (Pollytag) [kg]	800	800	800
Sand [kg]	360	360	360
Water [l]	240	240	240
Superplasticizer [l]	18	18	18
Aloxite - F80 [kg]	0	52.5	0
Aloxite - F280 [kg]	0	0	52.5

Research methods

For each concrete sample its volumetric density was defined and expressed as concrete mass per volume with pores. The compressive strength after 28 days of curing in a laboratory was tested on three cubic samples (sides of 100 mm). The load was applied without impact, steadily, so that the increase in load equalled the tension increase velocity of 0.6 MPa/s. As a result of the test, the highest load transferred by the sample was taken. The concrete resistance to abrasion was defined with the use of a Boehme grinding wheel according to norm PN-EN 14157/2005. Cubic samples with sides of 71 mm were prepared for the test and dried at 70 ±5°C till constant weight. Six samples of each concrete type were taken for the research. Before each test the volumetric density of the sample was defined, the sides measured to the nearest 0.1 mm and weighed to the nearest 0.1 g. Before starting the grinding wheel, 20 g of abrasive was put on the belt and the sample was loaded with an axial force of 294 ±3 N. Each sample underwent 16 cycles of 22 turns. The measure of wear is the change in volume of each sample. 6 cubic samples of each type (sides of 150 mm according to norm PN-EN 12390-8) underwent the water permeability test. The samples were dried till constant weight, put in a facility for water tightness testing and subjected to water pressure. After the test the samples were cracked in order to define the depth of water penetration in the concrete. The level of water tightness of the concrete was defined depending on the pressure indicator value and the water conditions. The microstructure of the concretes was tested with the use of scanning microscopy, with a scanning electron microscope S-3400 N.

RESEARCH RESULTS

Table 5 presents the results of the research on the physicomechanical properties of the lightweight concretes depending on the amount of aloxite. The addition of aloxite caused the sample mass to grow, which resulted in an increased volumetric density of the concrete. Comparison of the average values of compressive strength of particular types of concrete leads to the conclusion that the samples without additions have a lower compressive strength –25.1 MPa on average. The concretes with the additions of 80 fraction aloxite had a higher compressive strength. During their tests the result was 31.1 MPa. The most satisfying results were achieved by the concretes with 280 fraction aloxite –34.4 MPa. The increase in strength is related to the higher volumetric density of the concrete samples.

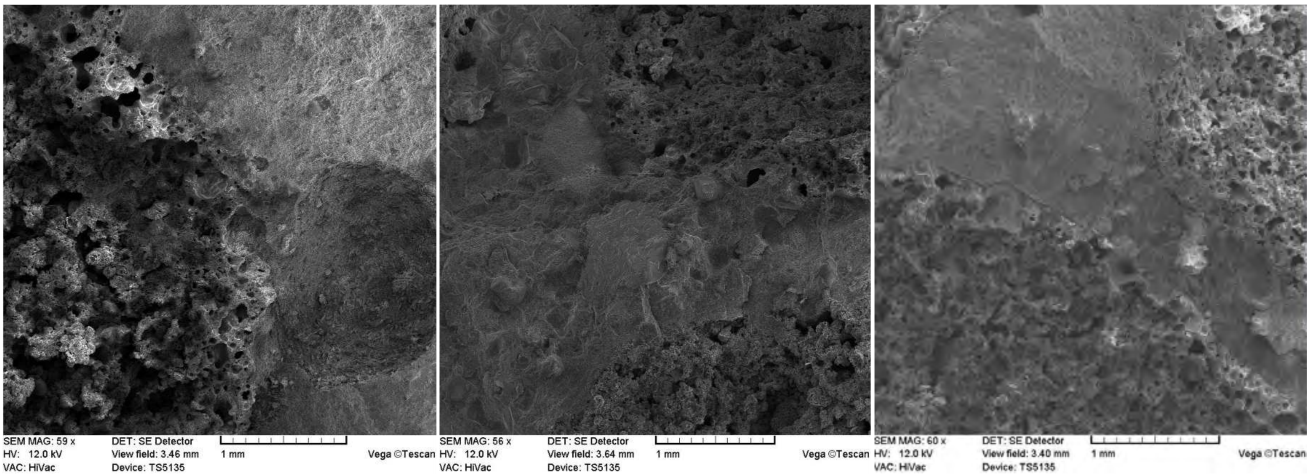
TABLE 5. **Physical and mechanical properties of LWC with and without aloxite additive**

TABELA 5. **Właściwości fizykomechaniczne betonów lekkich z i bez dodatku tlenku glinu**

	Type of sample		
	Reference concrete	Concrete with aloxite F80	Concrete with aloxite F280
Average density [g/cm^3]	1.592 ±0.023	1.658 ±0.023	1.658 ±0.023
Average compressive strength [MPa]	25.1 ±3.7	31.1 ±2.4	34.4 ±0.2
Average volume loss after 352 abrasive cycles [cm^3]	22.99 ±7.57	11.51 ±0.82	14.54 ±2.15
Water permeability depth [cm]	5.2	2.8	3.4

The compressive strength results correlate the abrasion resistance tests. It was shown that the average decrease in height in the abrasive tests for the referential samples equalled 4.2 mm, and the addition of aloxite improved the resistance to abrasion by about 30% for fraction 280 and by about 40% for fraction 80. The comparison of the water penetration depth in lightweight structural concretes is presented in Figure 2. During the water tightness tests of the concretes, the referential samples achieved water tightness class W8. It was verified that the application of an addition improves the water tightness of the concrete, and thus lowers the depth of water penetration by almost 50% in the case of aloxite fraction 80, and by 35% for fraction 280 in comparison with the referential samples.

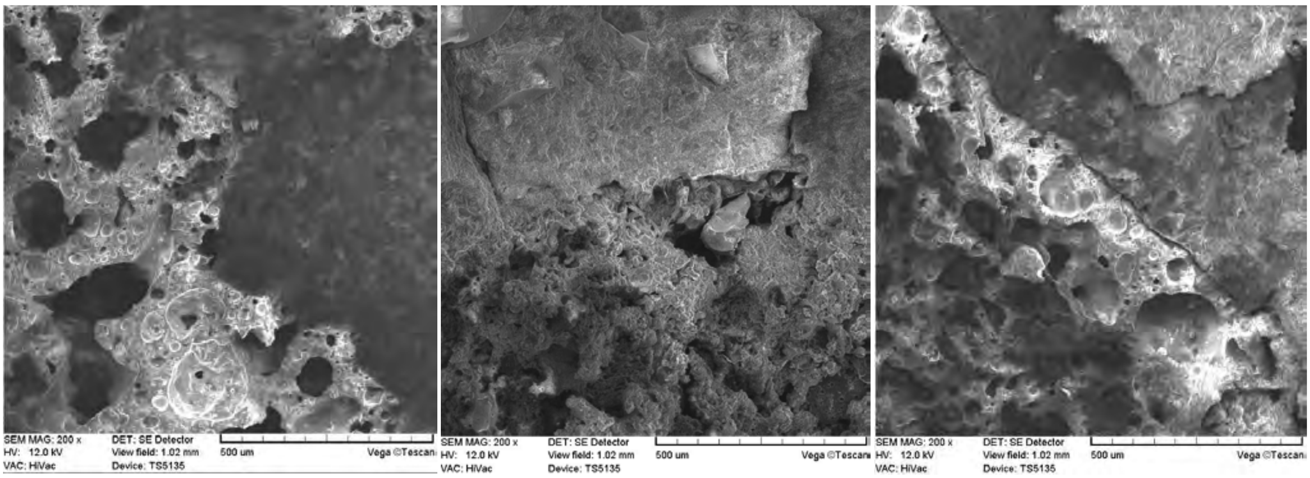
Figure 2 presents the microstructures of lightweight concretes with and without aloxite, whereas Figure 3 shows the images of the interfacial transition zones between the cement pastes and lightweight aggregate with and without aloxite, respectively. In the case of lightweight concretes with aloxite, there a clear line between the cement paste and porous lightweight aggregate is observed. On the contrary, for the concretes without aloxite, the interfacial transition zone between the cement paste and lightweight aggregate is diffused - the cement paste fills the pores of the aggregate grains. The best boundary was obtained in the case of cement paste with the aloxite additive characterized by the lowest particle size distribution - F280 (Fig. 3c). The aloxite additive densifies the cement paste microstructure, preventing water and cement paste from the filling the lightweight aggregate pores and as a consequence strengthens the interfacial transition zone between the lightweight aggregate and cement paste.



Microstructure of lightweight concrete without aloxite | Microstructure of lightweight concrete with aloxite F 80 | Microstructure of lightweight concrete with aloxite F 280

Fig. 2. Microstructure images of cement composites with and without aloxite

Rys. 2. Obrazy mikrostruktur kompozytów cementowych z dodatkiem syntetycznego tlenku glinu i bez dodatku tlenku



Without aloxite | With aloxite F80 | With aloxite F280

Fig. 3. Interfacial transition zone between lightweight aggregate and cement paste with and without aloxite

Rys. 3. Strefa kontaktowa pomiędzy lekkim kruszywem a zaczynem cementowym z syntetycznym tlenkiem glinu i bez tlenku

The results are compatible with those obtained by others researchers [10-12]. It is well known that the interfacial transition zone between the cement paste and aggregate is the most crucial parameter in determining concrete mechanical properties. In the case of a porous lightweight aggregate, the diffused interfacial transition zone increases the tension concentration and accelerates the occurrence of micro cracks. Therefore, any way of improving this drawback is advisable.

CONCLUSIONS

The research proved that the application of aloxite significantly influenced the physicomechanical properties of lightweight structural concretes. The best results were achieved by the concrete mixtures with fine-grained aloxite. The presence of fine-grained aloxite fractions contributed to condensation of the cement paste structure - the so-called filling effect - and strengthened the interfacial transition zone between the porous lightweight aggregate and cement paste. This improved the physicomechanical parameters of the cement composite. It has been proved that the compressive strength of concrete samples with an aloxite additive increases with regard to control samples by 25÷35% on average. Moreover, the addition of aloxite improves the abrasive strength of the concrete by about 30÷40% in comparison to concrete without any additions. Additionally, the research proved that the aloxite had a plasticizing influence, facilitated mixing the concrete mixture (especially with lightweight aggregate and high amounts of cement binder), which enabled the authors to receive a homogenous concrete structure, and improved the water tightness of the concretes by even 35÷50% in comparison to the referential concretes. The presented results showed that an aloxite additive can be a valuable component of lightweight structural concretes. In future research estimation of the concrete composition formulae by using both aloxite and fly ash additives as cement replacement in order to obtain high strength lightweight concrete with higher environmental resistance is planned.

REFERENCES

[1] Neville A.M., Properties of Concrete, Longman, England 1995.
[2] Mamlouk M., Zaniewski J.P., Materials for civil and construction engineers, Pearson, New Jersey, USA, 2011.
[3] Merikallio T., Mannonen R., Penttala V., Drying of lightweight concrete produced from crushed expanded clay aggregates, Cem. Concr. Res. 1996, 9, 1423-1433.
[4] Domagała L., The influence of porous aggregate on microstructure of the interfacial transition zone in lightweight concrete, Cement Wapno Beton 2011, 2, 101-114.
[5] Laplante P, Aitcin PC, Vezina D., Abrasion resistance of concrete, J. Mater. Civil. Eng. 1991, 1, 19-28.
[6] Naik T.R., Singh S.S., Hossain M.M., Abrasion resistance of high-strength concrete made with class C fly ash, ACI Mater. J. 1995, 6, 649-59.
[7] Fwa T.F., Paramasivam P., Thin steel fibre cement mortar overlay for concrete pavement, Cem. Concr. Comp. 1990, 3, 175-184.
[8] Żenczykowski W., Budownictwo ogólne. Tom IV: Fizyka budowli, Izolacje, Roboty wykończeniowe, Konstrukcje pneumatyczne, Wydawnictwo ARKADY, Warszawa 1970, 800.
[9] Domagała L., Projektowanie betonów lekkich wysokich wytrzymałości z kruszyw ze spiekanych popiołów lotnych, Cement - Wapno - Beton 2003, 5, 270-273.
[10] Elsharif A., Cohen M.D., Olek J., Influence of lightweight aggregate on the microstructure and durability of mortar, Cem. Concr. Res. 2005, 35, 1368-1376.
[11] Husem M., The effects of bond strengths between lightweight and ordinary aggregate-mortar, aggregate-cement paste on the mechanical properties of concrete, Mater. Sci. Eng. A, 2003, A363, 152-158.
[12] Wasserman R., Bentur A., Interfacial interactions in lightweight aggregate concretes and their influence on the concrete strength, Cem. Concr. Comp. 1996, 18, 67-76.

